One Hundred Consecutive Perfusions Over Five Hours

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Abstract

Complete surgical treatment of severe, diffuse coronary artery disease requires long perfusion time. We reviewed 100 consecutive perfusions longer than five hours (from a total of 675, operated May, 1980, through May, 1981). No case was excluded.

The 100 patients received 517 grafts, 217 coronary endarterectomies, 12 valves, and 12 aneurysmectomies; 98 had three vessel disease and 22 severe ventricular dysfunction. High flow, high pressure perfusion with physiologic blood gases was used.

Filters were used on cardiotomy return and arterial lines. Body temperature was kept 30–34°C at the preference of the surgeon. Intermittent ischemic arrest was used to preserve the myocardium. There were nine hospital deaths. Complications in the survivors included two instances of adult respiratory distress syndrome, one instance of stroke, and one of perioperative infarction. No patients were taken back for postoperative bleeding.

We conclude that, in view of the severity of disease, deaths and complications were well within acceptable limits.

Long perfusions, greater than five hours, did not contribute significantly to morbidity and mortality. Patients were perfused as long as necessary to achieve total revascularization.

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Introduction

Adequate surgical treatment of severe, diffuse coronary artery disease requires relatively long perfusion time. Surgical technique has evolved to the point where placing nine grafts is practical.[1] Where disease extends to the distal portion of an artery, endarterectomy is the only effective treatment.[2,3,4] Perfusion technique must be adequate to allow patients to be perfused as long as necessary to achieve total revascularization, regardless of the extent of coronary artery disease.

To assess the adequacy of our perfusion technique, we reviewed all patients undergoing coronary bypass (combined procedures included) from May 1980 through May 1981. During this period, a total of 675 bypass procedures were done. For 100 of these patients, or 14.8%, cardiopulmonary bypass exceeded five hours. These 100 patients are the subjects of this report.

Surgical Details—Study Group

Table 1 describes the study group and procedures performed. The total number of bypass grafts was 517 (5.2 per patient). There were 217 (2.2 per patient) coronary endarterectomies.

Other operative procedures included: 9 aortic valve replacements, 3 mitral valve replacements, and 12 ventricular aneurysm resections. Seven of the cases were reoperations.

Table 2 describes the extent of disease. We define a "diseased" coronary as one with 70% or more reduction in luminal diameter. There were no patients with single vessel disease, 2 patients

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TABLE 1
The Study Group

Surgery Date	May1980 through May1981*
Total Grafts	517 (5.2/Patient)
Coronary Endarterectomies	217 (2.2/Patient)
Valve Replacements	
Aortic	9 (9%)
Mitral	3 (3%)
Ventricular Aneurysms	12 (12%)
Reoperations (One or More Times)	7 (7%)

* During this period, 675 total bypass procedures were done 100/675 = 14.8%

with double vessel disease, and 98 patients with triple vessel disease. Eighty patients had ejection fractions recorded before surgery. Thirty-eight (48%) patients exhibited normal left ventricular function (EF > 50%), 20 (25%) patients had moderate left ventricular dysfunction (EF 35–50%), and 22 (27%) patients had *severe* left ventricular dysfunction (EF < 35%).

Perfusion Technique

Table 3 is a summary of our perfusion technique and materials. All of the cases were perfused with double roller pumps,[a] hybrid bubble oxygenators,[b] 20 micron screen arterial line filter,[c] packed dacron +20 micron screen cardiotomy filter,[c] and silicone rubber pump headers 5/8 inch internal diameter.[d]

The prime solution consisted of 3,000 milliliters of balanced electrolyte solution, adjusted to pH 7.4,[e] 5,000 units of heparin,[f] and 25 grams of sodium mannitol.[g] Gravity drainage was from both vena cavae;[b] return was into the ascending aorta through a 9.5 mm. rigid disposable cannula.[h] The heart was vented for left ventricular decompression via cannulation in the aortic root.[b]

Body temperature was maintained at between 30 and 34°C (rectal). Units of additional solutions added to the perfusate during bypass averaged (per patient): whole blood, 2.0; packed cells 0.77, albumin 0.61. Total blood products added averaged 3.4 units per patient. In addition to the blood products, an average of 5 liters of crystalloid were added.

Mean arterial pressure averaged 80 mmHg with a standard deviation (S.D.) of 10 mmHg. The mean perfusion flow rate was 67 ml per kilogram body weight per minute with a standard deviation of 9 ml. Arterial blood gas data revealed a mean pH of

TABLE 2

EXTENT OF DISEASE Number of diseased vessels (70% of diameter)	
Single vessel	0
Double vessel	2
Triple vessel	98
LEFT VENTRICULAR FUNCTION Ejection Fraction—(80 Patients)	
Normal Function (50%)	38 (48%)
Moderate Dysfunction (35–50%)	20 (25%)
Severe Dysfunction (5–35%)	22 (27%)

TABLE 3
Materials and Methods of Perfusion

PRIME AND EQUIPMENT		
Prime:	Balanced Electrolyte Solution	3,000 ml.
	Heparin	5,000 Units
	Mannitol	25 gm.
Equipment:		
	Pump:	Roller
	Oxygenator:	Hybrid Bubble
	Arterial Filter:	20 Screen
	Cardiotomy Filter:	Packed Dacron & 20 Screen
	Arterial Pump Head:	5/8" I.D. Silicone Rubber
PERFUSION DATA		
Mean Arterial Pressure		80 mmHg, SD 10*
Mean Pump Flow Rate		67 cc/kgm/min, SD 9
pH		7.37, SD .04
PO2		170 mmHg, SD 42
PCO2		40 mmHg, SD 3
Hematocrit		24%, SD 2%
Urine Output		3,725 cc, SD 2,325
Perfusion Time		342 min, SD 40
Rectal Temperature		30–34 C**
* SD = Standard Deviation		
** Surgeon's Preference		
SOLUTIONS ADDED DURING BYPASS		
Whole Blood		2 units/patient*
Packed Cell Mass		.8 units/patient
Normal Serum Albumin		.6 units/patient
Total Products		3.4 units/patient
Crystalloid		5700 ml/patient
* All units = average		

[a] Pemco, Inc., Cleveland, OH 44131
[b] Bard Cardiopulmonary Division, Santa Ana, CA 92700
[c] Extracorporeal Medical Specialities, King of Prussia, PA 19406
[d] Fluorocarbon, Sunnyvale, CA 94086
[e] Travenol Laboratories, Deerfield, IL 60015
[f] Elkins-Sinn, Inc., Cherryhill, NJ 08034
[g] Innenex, Chagrin Falls, OH 44022
[h] Sarns, Inc., Ann Arbor, MI 48103

7.37 ± .04 S.D., and a mean pO_2 of 170 ± 42 mmHg S.D. (We believe 170 mmHg pO_2 is not physiologic[5], and are now beginning to use a membrane oxygenator for better control of pO_2.) The mean pCO_2 was 40 ± 3 mmHg, and hematocrit 24% mean, ±2%. Average total urinary output on pump was 3,725 milliliters ± 2,325 milliliters; mean perfusion time was 5 hours, 42 minutes or 342 minutes ± 40 minutes.

Results

Table 4 summarizes the deaths and complications. There were nine surgical deaths, all attributed to low cardiac output. The intra-aortic balloon pump was used on eight of the persons who died. In addition to these nine, three other patients required the intra-aortic balloon pump. The only other complications were two instances of adult respiratory distress syndrome and one instance of perioperative myocardial infarction. No patients were returned to surgery for postoperative bleeding. These death and complication rates are well within acceptable limits for patients with far advanced and severe coronary artery disease.[6]

Discussion & Summary

These data strongly suggest that long perfusions do not per se contribute significantly to morbidity and mortality. This is not to be confused with long perfusion necessitated because of technical difficulties. Overall statistics for all 675 bypass patients operated on during the study period were as follows: 48.5% received coronary endarterectomy, 23.7% were second reoperations, and an average of 3.9 bypass grafts were placed. Average perfusion time was 250 minutes.

Of the 304 patients who had ejection fractions recorded before surgery, 150 (49%) had normal left ventricular function (EF > 50%); 78 (26%) had moderate dysfunction (EF < 35–50%); and 76 (25%) *severe* left ventricular dysfunction (EF < 35%). Surgical (30 day) mortality was 5.0%.

The overall statistics between the study group and all patients operated during the same time period show similar results, except that 81% of the study group, versus 48% of all patients, received coronary endarterectomy. The study group averaged 5.2 grafts per patient versus 3.9 for all patients. Surgical mortality was 9% in the study group and 5% for all patients. Severe, diffuse disease is associated with higher surgical mortality.

Nevertheless, we have shown that patients with severe disease can be perfused as long as necessary to achieve the total revascularization. Factors we believe are important in successful long perfusion are summarized in Table V and discussed as follows:

Physiologic blood flows and pressures This is particularly important in preventing cerebral complications, because these patients have atherosclerosis to some extent throughout their bodies. We perfuse chronic hypertensives at higher pressures.

The effectiveness of cardioplegia is frequently compromised by high flows and pressures, which accelerate the removal of the cardioplegic agent through non-coronary collateral.[7] This is one of the reasons we do not use cardioplegia.

Hematocrit 22–24% This is the only variable we intentionally allow to go out of the physiologic range. As the hematocrit drops, so does blood viscosity. This allows more flow for a given pressure and adequate oxygen delivery is maintained. If the hematocrit drops below 20%, the viscosity changes little but the oxygen carrying capacity decreases markedly.[8,9] From our experience, we have found that 22–24% is adequate to deliver oxygen yet low enough to minimize use of homologous blood.

TABLE 4
Deaths and Complications

	Fatal	Non-Fatal
Low Cardiac Output	9	3*
Major Stroke	0	1
Adult Respiratory Distress Syndrome	0	2
Perioperative Myocardial Infarction	0	1
Reoperation for Bleeding	0	0

* Requiring Intra-aortic Balloon Pump

TABLE 5
Technique Summary—Important Points

1. High Flow Rates	60–80 cc/kgm/min
2. High Arterial Pressure	80 mmHg*
3. Physiologic Blood Gases	pH 7.40, PO2 100–125 mmHg, PCO2 40–45 mmHg
4. Hematocrit	22–24%
5. Arterial and Cardiotomy Filters	
6. Changes Only of Proven Benefit	

* Higher Mean Pressure for Hypertensive Patients

Physiologic blood gases With the maintenance of physiologic flows and moderate hematocrit, little or no lactic acid accumulates and pH is maintained.[10] This series represents about 550 hours of perfusion. Not one ampule of bicarbonate was added on bypass, yet the pH was maintained at 7.37+/−.04. A drop in pH indicates inadequate perfusion and should be corrected by increasing flow, not adding buffer.

We prefer to keep the pCO_2 on the high side of 40 mmHg. Low pCO_2 causes a reduction in cerebral flow, and we know of no detrimental effects of a slightly elevated pCO_2. In this study our average pCO_2 was 40 mmHg. We would prefer to keep the pCO_2 at a minimum of 40 mmHg. Our preferred range of pO_2 is 100–140 mmHg, primarily because of the coronary vasoconstrictive effects of elevated pO_2[5,11,12] but also because we try to avoid operating outside of the physiologic range without good reason. In this study, the pO_2 *averaged* 170 mmHg; we would prefer a *maximum* of 170 mmHg.

It appears that there is simply no way to attain the blood gas levels we consider ideal; not with currently available gas interface oxygenators (except, of course, by mixing nitrogen with the O_2). Therefore, we have started evaluating membrane oxygenators. They show great promise of improved control of blood gases.

Cardiotomy and arterial line filters Use of filters is based on the fact that the largest formed element in blood is 13 microns. Anything larger is not blood and should be removed.[13,14] We have used filters since their introduction and feel that they are an essential element in keeping cerebral and lung complications low.

Making changes to the system only after benefit has been proven We do not evaluate a change unless it holds the promise of a significant improvement. Similarly, we do not adopt a change unless we are convinced that it is better than the way we were doing it before. Minor and seemingly insignificant changes, especially when allowed to amass, can deteriorate the performance of a system.

Intermittent ischemic arrest Regardless of how well the body is perfused, it is to no avail if the heart will not eventually take over. Our perfusion technique and myocardial protection technique or intermittent ischemic arrest—work hand in hand. Non-coronary collateral circulation can remove cardioplegic solution from the heart necessitating reduction in systemic flow. Physiologic flow, pressure, pO_2, and maintenance of rhythm during reperfusion are key and essential elements to the success of intermittent ischemic arrest. This perfusion technique is used for mitral valve replacements as well. During aortic valve replacement coronary perfusion is employed to fill the requirements of intermittent ischemic arrest.

Summary

From our experience, a prolonged cardiopulmonary bypass time, associated with major revascularization and/or combined procedures did not contribute to the overall operative risk. We attribute these results, in part, to the adequacy of perfusion.

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